# OXYGEN-ENRICHED COMBUSTION OF A COAL-WATER FUEL

by

Timothy S. McIlvried, Alan W. Scaroni, and Robert G. Jenkins

Fuel Science Program
Department of Material Science and Engineering
The Pennsylvania State University
University Park, PA 16802

## INTRODUCTION

Several successful test firings have been performed with coal-water fuels (CWF's) in industrial boilers. However, even with advances in atomization and burner design, there are still inherent limitations associated with CWF's which cause decreased combustor performance. These include:

1) Temperatures and heat liberation from CWF flames are lower than those of oil flames. This is due, mainly, to the high water concentrations, which must be vaporized.
2) Successful ignition and flame stabilization of CWF's usually require high primary air preheat temperatures and/or a pilot flame.
3) Ignition delay and burnout times of CWF droplets are longer than those of oil droplets. The residence time of CWF droplets in oil fired boilers is usually not sufficient for complete carbon burnout. Thus, the CWF firing rate must be reduced, resulting in a derating of the boiler.

One means of overcoming, or at least reducing, the combustion problems associated with CWF's is oxygen enrichment of the combustion air. Moderate amounts of oxygen enrichment, usually between 1-4 volume percent, have been used in industry to either boost production levels or improve combustion efficiency in pulverized coal and oil fired boilers (1). Oxygen enrichment increases the partial pressure of oxygen leading to acceleration of the combustion rate and, thus, the rate of char burnout of the CWF droplets. Correspondingly, there is a decrease in the total amount of nitrogen in the combustion air, which reduces the volume of the air and flue gases. This in turn, causes an increased residence time of the CWF droplets because of lower gas velocities. Both increased combustion rate and longer residence time will help offset some of the derating associated with converting to CWF's. This study is aimed at determining the effect that a 2% increase in the oxygen content of the primary combustion air will have on the combustion characteristics of a CWF.

## EXPERIMENTAL

A horizontally fired laboratory scale combustor, designed and built at Penn State to fire fuel oil, was modified to fire CWF's (2,3). Using this combustor, the effect of enriching the oxygen content of the primary air on the heat distribution in the furnace, the quantity of unburned carbon in the flyash and pollutant formation ($NO_x$ and $SO_2$) were investigated.

The CWF used was supplied by The Atlantic Research Corporation, Fredericksburg, Virginia. Analyses of the CWF and parent coal are given in Table 1. The origin of

TABLE 1
ANALYSES OF THE CWF

| | AS RECEIVED (wt%) | DRY BASIS (wt%) |
|---|---|---|
| C | 57.4 | 80.8 |
| H | 3.4 | 4.8 |
| N | 1.1 | 1.6 |
| S | 0.5 | 0.7 |
| O (by difference) | 4.3 | 6.0 |
| ASH | 4.3 | 6.1 |
| H2O | 28.9 | - |

Higher Heating Value $2.44 \times 10^7$ J/kg (10,500 BTU/lb)

PROXIMATE ANALYSIS (DRY BASIS)

| VM | ASH | FIXED CARBON |
|---|---|---|
| 30.9% | 6.1% | 63.0% |

the parent coal is unknown but the analyses are typical of a high volatile eastern bituminous coal. The CWF has a solids loading of 70 wt% and a higher heating value of $2.44 \times 10^7$ J/kg (10,500 BTU/lb). Thus, the CWF is typical of many of those that are currently under consideration by industry. The furnace was operated at a firing rate of 48 kW (164,000 BTU/lb). Oxygen enrichment was achieved by combining a stream of pure oxygen with the combustion air in order to increase the oxygen content to the desired 23% concentration. The oxygen/fuel ratio was varied from 95% to 115% theoretical oxygen. Centerline furnace temperatures were measured at various axial distances along the combustor using shielded thermocouples. Stack gases were continuously monitored for $O_2$, $CO_2$, CO, $NO_x$, and $SO_2$. Flyash samples were analyzed for carbon content.

Furnace preheat and CWF ignition were achieved by a methane pilot flame. It should be noted that stable CWF flames were not able to be maintained without pilot flame support. Thus, the methane pilot flame was maintained during all trials and provided approximately 25% of the total heat input to the combustor.

## RESULTS

Combustion trials were performed on the CWF with normal air and air enriched to 23% oxygen (2% oxygen enrichment). A 2% increase in oxygen content of the primary combustion air provided an 8.7% decrease in the volume of combustion air required and a 7.9% decrease in the volume of flue gases produced. Figure 1 shows higher furnace temperatures for the oxygen enriched case. There was approximately a 60 K increase at 5% excess oxygen. This increase in temperature appears to be quite constant over the length of the combustor. The amount of carbon in the flyash was reduced by about 5% at this excess oxygen level. The oxygen enriched flames also appeared visually brighter and closer to the burner (i.e. a shorter ignition delay).

Sulfur oxides are formed when sulfur in the fuel is oxidized during the combustion process. Figure 2 shows $SO_2$ emissions as a function of excess air (normalized to a 0% excess air basis and taking into account the reduced volume of flue gas in the oxygen enriched cases). It was found that $SO_2$ concentrations were virtually independent of amount of excess air or oxygen enrichment for the fuel lean flames. However, the $SO_2$ concentrations appear to be increased for the oxygen enriched fuel rich flame.

As is well known, $NO_x$ is formed in two ways during combustion; that is by oxidation of atmospheric nitrogen (thermal $NO_x$) and oxidation of nitrogen in the fuel (fuel $NO_x$). The formation of thermal $NO_x$ is very temperature dependent and is not considered to be a significant source of $NO_x$ formation at temperatures below about 1770 K (4). The maximum temperature reached in the experimental combustor was about 1450 K therefore, most of the $NO_x$ was assumed to be fuel $NO_x$. Figure 3 shows the variation of $NO_x$ with percent excess air for both the normal and oxygen enriched combustion. $NO_x$ concentrations were approximately 70 PPM higher in the fuel lean oxygen enriched flames. As the flames become more fuel rich the $NO_x$ concentrations in the oxygen enriched flames somewhat approach the concentrations found in the ambient air flames.

## CONCLUSIONS

Oxygen enriched combustion of a CWF was studied in a small scale (48 kW) combustor. It was found that a 2% increase in oxygen content of the combustion air produced:

1) Increase of about 60 K in furnsce temperature.
2) More luminous flame with shorter ignition delay.
3) Approximately a 5% reduction of carbon in the flyash
4) No effect on $SO_2$ formation in fuel lean flames.
5) Somewhat higher $NO_x$ emissions for fuel lean flames but only slightly higher $NO_x$ concentrations for fuel rich flames.

ACKNOWLEDGEMENTS

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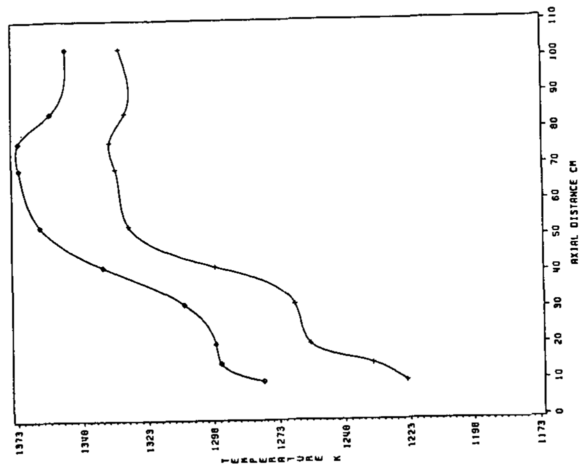


Figure 1. Centerline Furnace Temperature. +'21 % Oxygen; ◇ 23% Oxygen.

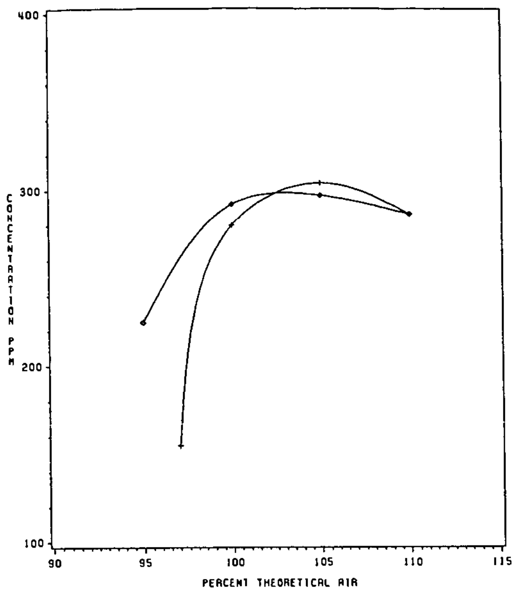


Figure 2. Sulfur Dioxide Concentration Versus Percent Theoretical Air on an Oxygen Free Basis. + 21% Oxygen; ◇ 23% Oxygen.

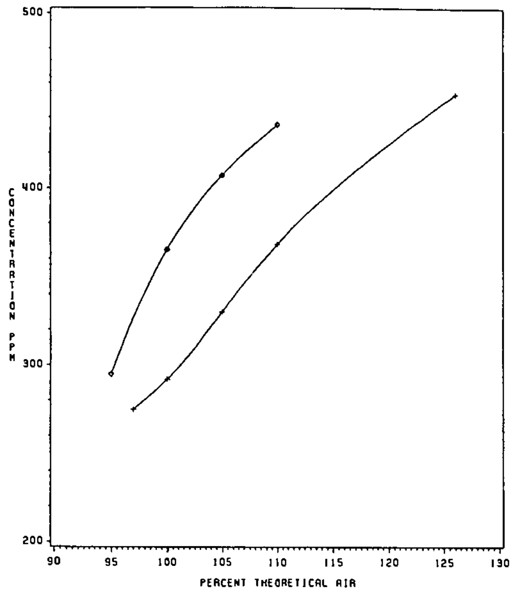


Figure 3. $NO_x$ Concentration Versus Percent Theoretical Air on an Oxygen Free Basis. + 21% Oxygen; ◇ 23% Oxygen.